Original Research Article

Experimental Investigation on Combustion Characteristics of LHR and Conventional Engines Using Tobacco and Cotton Seed methyl ester blend

ABSTRACT

Aims: This study presents an experimental investigation into the combustion characteristics of Tobacco Seed Oil Methyl Ester (TSOME), Cotton Seed Oil Methyl Ester (CSOME) and its blend as biodiesel alternatives in both conventional and Low Heat Rejection (LHR) engines.

Study Design: The LHR engine, incorporating thermal barrier Ni90 insert is inserted on piston crown to enhance combustion efficiency by reducing heat loss. **Place and Duration of Study:** The Experiment was conducted in Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad, Telangana State, India between February 2023 and October 2024.

Methodology: The research focuses on comparing key combustion parameters such as in-cylinder pressure and heat release rate (HRR) for TSOME, CSOME and its blend in both engine configurations across varying load conditions.

Results: The experimental results indicate that both biodiesel fuels and its blend demonstrate competitive combustion characteristics near to conventional diesel. The LHR engine with blend outperformed the conventional engine in terms of peak in-cylinder pressure and heat release rate, with a noticeable reduction in ignition delay and combustion duration and also exhibited marginally higher peak pressures and combustion efficiency compared to CSOME and TSOME. **Conclusion:** The findings suggest that the combination of LHR technology and blend of TSOME and CSOME blend offer a viable solution for improving engine combustion efficiency while reducing reliance on fossil fuels.

Key words: *TSOME, CSOME, Pressure and Heat release rate*

1. INTRODUCTION

The growing concerns about the depletion of fossil fuel reserves and the environmental damage caused by their combustion have led to an increasing demand for sustainable energy alternatives. Among these alternatives, biodiesel stands out as a renewable and cleaner fuel option. Biodiesel is produced from various renewable feedstocks, primarily vegetable oils and animal fats, and has the potential to significantly reduce greenhouse gas (GHG) emissions compared to conventional fossil fuels. Its renewable nature, biodegradability, and lower environmental impact make it an attractive substitute for petroleum-based diesel.

In the search for non-food feedstock's that do not compete with agricultural resources for human consumption, tobacco seed oil and cotton seed oil have emerged as promising feeds to CI engines. These non-edible oils, which are by-products of other agricultural processes, can be converted into biodiesel via the transesterification process. This process chemically alters the oils into fatty acid methyl esters (FAME), producing biodiesel with properties that closely resemble traditional diesel fuel. The use of such feedstock'shelps minimize competition with food production while providing a sustainable and eco-friendly fuel alternative.

The combustion process in a Compression Ignition (CI) engine, or diesel engine, is unique due to its reliance on auto-ignition rather than a spark. CI engines operate on the principle of compression ignition, where air is highly compressed, raising its temperature to the auto-ignition point of diesel fuel. Diesel fuel has a high cetane number, which makes it suitable for auto-ignition at the temperatures reached through compression alone and theoretical combustion stages demonstrated in figure 1.

In a Compression Ignition (CI) engine, fuel atomization plays a critical role in determining the combustion process's efficiency and its characteristics. Atomization is the process by which fuel is broken down into fine droplets as it is injected into the combustion chamber. This fine spray of fuel droplets allows for a larger surface area in contact with air, which is essential for thorough mixing of fuel and air before ignition.

When fuel is well-atomized, it creates an even mixture with air, which leads to more complete and efficient combustion. This results in higher combustion pressure and heat releasing rate, maximizing power output while reducing fuel consumption. Additionally, finer atomization minimizes unburned fuel, helping to decrease emissions of pollutants. The atomization property can be influenced by the higher viscosity of biodiesel which can lessen the combustion efficiency. The ignition delay (ID) for biodiesel will be lower than diesel since biodiesel has more cetane than diesel. The existence of oxygen content in biodiesel increases combustion efficiency, leading to a rise in heat release rate most cases.

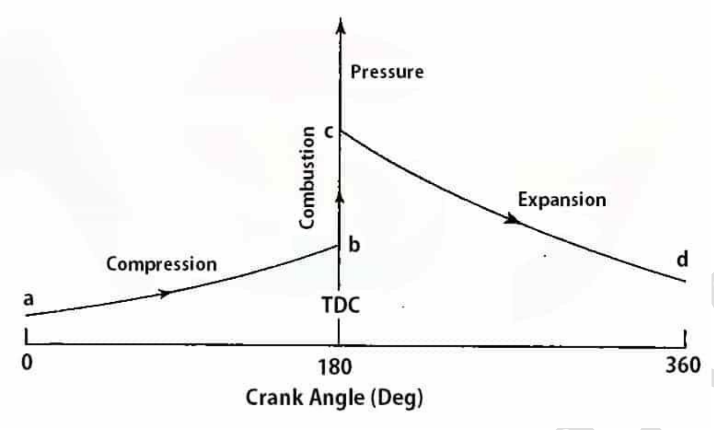


Fig.1. Theoretical Pressure vs Crank angle diagram [1]

Blended fuels improve in the atomization of fuel and showed better combustion characteristics in a Compression Ignition (CI) engine, the combustion behaviour is strongly influenced by the type of fuel blend used, as different fuels have varying chemical compositions, physical properties, and combustion characteristics. Blending diesel with biofuels like biodiesel or alcohols (e.g., ethanol, butanol) alters properties such as cetane number, viscosity, oxygen content, and calorific value, which in turn affect how the fuel burns in the engine.

The cetane number of a fuel blend is a measure of its ignition quality. Higher cetane numbers reduce ignition delay, leading to a smoother and faster combustion process. Biodiesel typically has a higher cetane number than conventional diesel, meaning biodiesel blends often ignite more readily in CI engines. This can improve engine performance and reduce noise, though in some cases, it may also lead to a quicker combustion phase, impacting thermal efficiency. Biofuels like biodiesel naturally contain oxygen within their molecular structure. When blended with diesel, this oxygen helps promote more complete combustionby aiding fuel oxidation. This often results in lower emissions. Fuel viscosity impacts atomization during injection. Higher-viscosity fuels, like those in biodiesel-diesel blends, produce larger fuel droplets that don't vaporize as quickly, potentially leading to incomplete combustion if atomization is insufficient. Biofuel blends generally have slightly lower energy content than pure diesel due to their lower calorific value. This means that for the same volume of fuel, the energy output might be slightly reduced impacting overall engine performance, if the blend ratio is high. However, this impact is often minor and can be compensatedby optimizing the engine's combustion parameters, such as injection timing.

Additionally, Low Heat Rejection (LHR) engines have been developed to address the inefficiencies of conventional internal combustion engines, particularly the large portion of heat energy that is lost through engine components such as the cylinder walls, cylinder head, and piston crown. LHR engines are designedto retain more heat within the combustion chamber, which is achieved by applying ceramic coatings and ceramic inserts to key engine parts like the piston crown and cylinder head. These materials act as thermal barriers, reducing the amount of heat transferred away from the combustion chamber. By improving the thermal efficiency of the engine, LHR technology allows for more complete combustion of the fuel, leadingto better fuel utilization and enhanced combustion stability. This is especially beneficial when using biodiesel blends, as the higher temperatures promote efficient fuel breakdown and reduce ignition delays often observed with biodiesel fuels.

In summary, using fuel blends in CI engines can enhance combustion efficiency, reduce certain emissions, and improve engine durability due to cleaner burning characteristics. However, these benefits need to be balanced with adjustments to engine design or operating parameters to address challenges increased NO$_X$ emissions and potential power reductions. Overall, the integration of LHR technology with biodiesel fuels, such as those derived from tobacco seed oil and cotton seed oil, holds great potential for improving engine efficiency and promoting sustainable fuel solutions. By combining these innovations, there is an opportunity to address both energy and environmental challenges more effectively. This study aims to evaluate the combustion characteristics of TSOME and CSOME biodiesel blends in conventional and LHR engines, comparing their performance with conventional diesel under varying engine loads.

2. Materials and Methodology

The experimental setup utilized for investigating combustion characteristics Conventional and LHR diesel engines [14&15] with TSOME and CSOME blend as fuels is depicted in Figure 2, while the configurations of the engines are detailed in Table 1 and properties of fuels are described in Table 2. To measure inside cylinder pressure Piezoelectric pressure gauge is mounted, while the fuel consumption and air consumption was determined using the burette and air-box method with naturally aspirated and engine was fitted with a water-cooling system, and the inlet water temperature was controlled at 30°C by regulating the flow rate. Experiments were conducted at the various speeds from 3000 to 1000 and a CR of 16.5:1.

Table 1 .Testing Engine Technical details

Engine parameters		Specifications
Engine Type		Single cylinder 4 stroke CI Engine
Manufacturer		Kirloskar
Maximum power		3.8 kW at 1500RPM
Bore/Stroke		80/110mm
Specific volume		0.552 liter
Compression ratio		16.5:1
Cooling type		Water cooling
Air Gap		3mm
Insulated insert	Material	Ni90
	Thickness	5mm

The engine was manually cranking to start engine, with conventional fuel supplied initially until a steady state. The water flow rate to the engine cooling jacket was maintained at approximately 9 LPM. Once the engine attained a steady state, the test fuel was introduced into the engine from a separate fuel tank. Load application was achieved using an eddy current dynamometer and load conditions of 0 to 7kgs by increasing 20% gradually for each experiment cycle using TSOME and CSOME blend. Various parameters such as inside cylinder pressure, load, and inside cylinder temperature were recorded under all conditions.

Table 2. Properties of prepared Fuels

Fuel Properties	Units	CSOME	TSOME	TCOME
Density	$\mathbf{g/cc}$	0.9	0.887	0.8935
Specific gravity	-	0.93	1.178	1.054
Calorific value	$\mathbf{kj/kg}$	41950	38000	39975
Cetane Number	-	49	52.1	50.55
Viscosity	$\mathbf{mm^2/sec}$	29.22	0.493	14.8565
Fire point	℃	680	186.1	433.05
Flash point	℃	606	163.5	384.75
Boiling point	℃	319	325	322

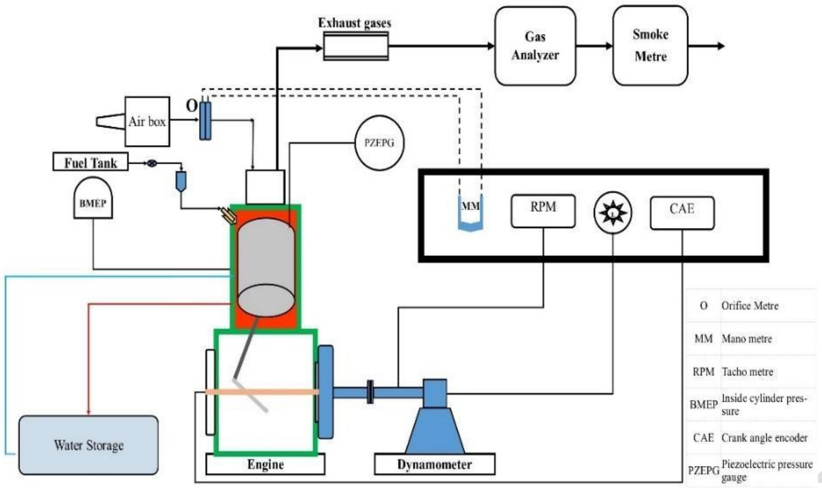


Fig. 2. Experimental Schematic layout

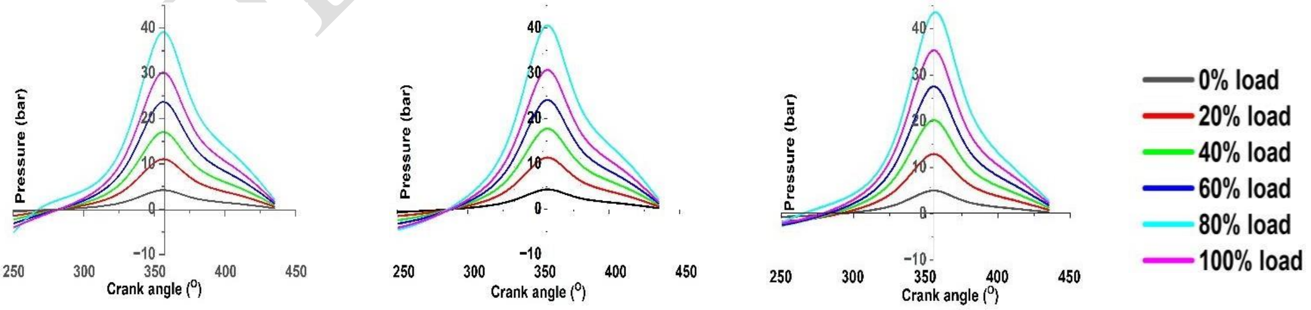
3. RESULTS AND DISCUSSION

The combustion characteristics were systematically investigated of single-cylinder; four-stroke CI engine fuelled with CSOME, TSOME and its blend in the current study. Several combustion parameters (Cylinder Pressure, NHRR) are evaluated of the CSOME, TSOME and its blend and compared at different loading conditions. All tests have been carefully tested and the tests are repeated 3 times and the average data is used for reliable results.

3.1 Cylinder pressure

Figure 3 and 4 presents the variation in in-cylinder pressure with respect to the crank angle under different engine loads for both the conventional and Low Heat Rejection (LHR) engines using Cottonseed Oil Methyl Ester (CSOME), Tobacco Seed Oil Methyl Ester (TSOME) and its blend (TCOME). It is evident from the figures that the pressure patterns across all load conditions for all samples follow a similar trend, characteristic of the combustion process in both conventional and LHR compression-ignition engines.

The Figure 3 also highlights the peak in-cylinder pressure variations at various engine loads for three different fuels. Generally, the peak cylinder pressure is primarily influenced by the mass of fuel burned during the uncontrolled combustion phase and calorific value of fuel which affects the rate of pressure rise in compression-ignition engines. As engine load increases, more fuel is injected into the cylinder, leading to a gradual rise in in-cylinder pressure. As observed in Figure 3, the highest in-cylinder pressures for both fuel samples occur at 80% load, with the engine operating at average speed of 1400 rpm.



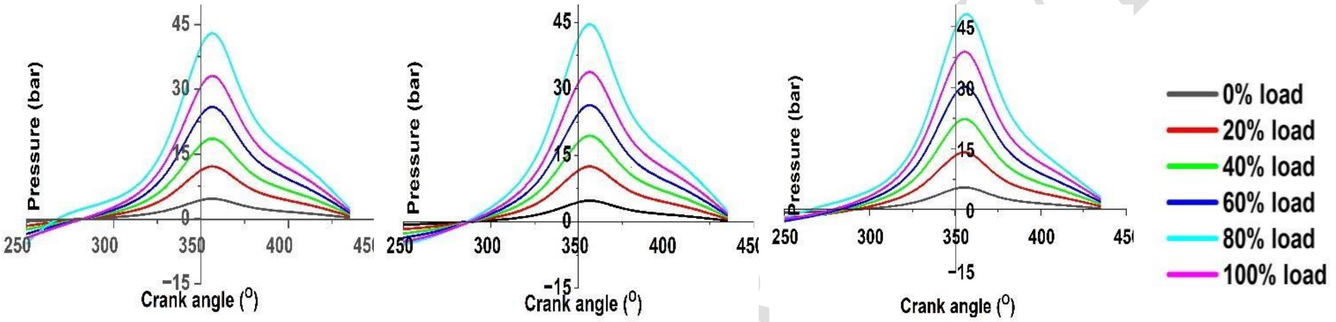
a. For CSOME b. For TSOME c. For TCOME

Fig. 3. Variation of Pressure with respect to Crank angle for Conventional engine

Maximum pressures recorded were 45.2, 43.57 and 48.32 bar for TSOME, CSOME and TCOME in the conventional engine at 80% of load, with peak pressures occurring near Top Dead Centre (TDC). From thiswe can said that as the addition of TSOME to CSOME combustion pressure increased due to thermo physical characteristics, cetane value and calorific value of blend. It is expected that peak pressure would occur around TDC, reducing the ignition delay period. Additionally, the ignition delay and the amount of fuel burned during the uncontrolled combustion phase play a significant role in reaching the maximum in-cylinder pressure.

Oxygen fraction in the blend displays a predominant role in the combustion process. The existence of oxygen in biodiesel, due to which combustion is relatively complete despite the lower calorific value of biodiesel, is another cause of the closer peak pressure of biodiesel to that of conventional fuels. At 80% load conditions, the temperature also rises with respect to pressure leading to a higher rate of evaporation and enhanced combustion.

The LHR engine running on biodiesel blends tends to ignite fuel earlier due to factors as higher cetane numbers and reduced heat loss compared to the conventional engine. As a result, ignition occurs later in the conventional engine. Maximum pressures recorded were 49.63, 47.83 and 53.31 bar for TSOME, CSOME and TCOME in the conventional engine at 80% of load, with peak pressures occurring near Top Dead Centre (TDC) shown in figure 4. The LHR engine consistently demonstrated higher peak in-cylinder pressures at all load conditions compared to the conventional engine. This can be attributed to the improved insulation provided by the thermal barrier materials used in the LHR engine, which reduces energy loss and leads to more efficient combustion. One of the critical factors that influences ignition delay is the fuel's cetane number, which is higher in biodiesel blends, contributing to a shorter ignition delay in the LHR engine.



a. For CSOME b. For TSOME c. For TCOME

Fig. 4. Variation of Pressure with respect to Crank angle for LHR engine

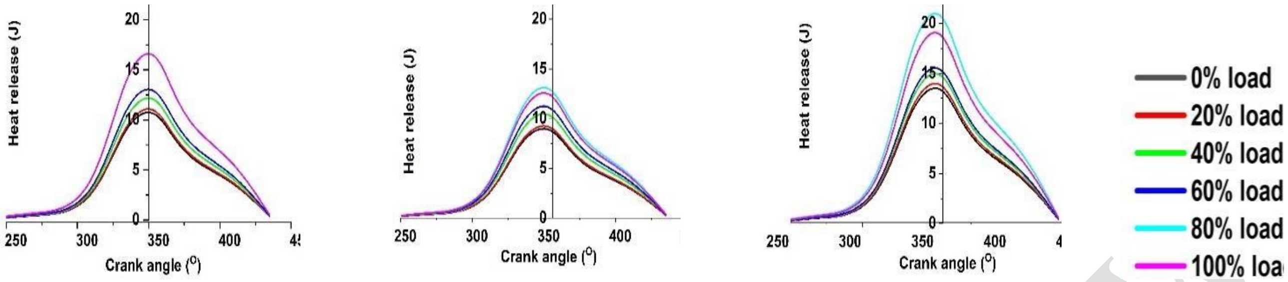
In summary, the Low Heat Rejection (LHR) engine demonstrated enhanced combustion performance, characterized by increased in-cylinder pressures and shortened ignition delay. These improvements are primarily due to the engine’s ability to retain more heat, which supports a more efficient combustion process. Additionally, the biodiesel blends contribute positively to combustion due to their higher oxygen content, which facilitates better fuel oxidation. This combination of heat retention and enhanced combustion properties with biodiesel blends allows the LHR engine to achieve more effective fuel utilization, leading to more stable combustion and potentially lower emissions compared to conventional engines.

3.2 Heat release rate

The heat release rate (HRR) can be estimated from the gas pressures takes place in the cylinder during the combustion process in accordance with the first law of thermodynamic. The variation of heat release rate with respect to the crank angle for conventional and LHR engine at different engine loads for the distinct fuel samples was illustrated in Figure 5 and 6.

The NHRR is initially low and after the start of combustion becomes high. The low value is due to the evaporation of the fuel accumulated during the period of ID. Furthermore, the wall temperature augments and charge temperature boosts with increasing load, and the combustion chamber accumulates more fuel because this charge ignites earlier and increases the NHRR. It is found that the peak of NHRR takes place slightly before in the case of conventional engine at 100% loads for CSOME as shown in Fig. 5(a), similarlyfor TSOME and blend at 80% of load shown in figure 5(b) and 5(c), It is noticed that there is lessening in the NHRR with a rise in load. At a load of 80%, higher heat is released at the premixed combustion phase because the Ignition Delay period is prolonged and the collected fuel increases during this period.

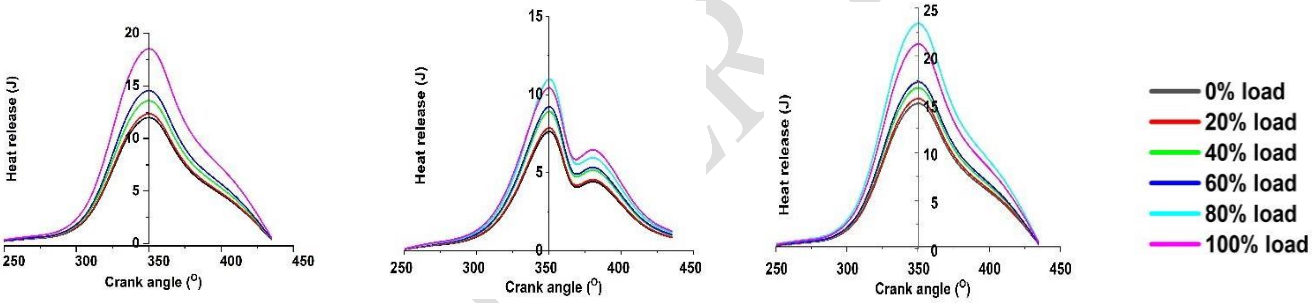
The increase in fuel utilization during the premixed combustion phase leads to a heightened net heat release rate (NHRR), which, in turn, compresses the duration of the diffusion combustion stage. In conventional engines using individual and blended biodiesel fuels namely Cotton Seed Methyl Ester (CSOME), Tobacco Seed Methyl Ester (TSOME), and their combined blend, the peak NHRR values recorded are 17.73 J/°CAfor CSOME, 13.99 J/°CA for TSOME, and 22.38 J/°CA for the CTOME blend. This data indicates that incorporating CSOME into TSOME can improve the overall combustion rate and intensify the heat releaserate, primarily due to the enhanced calorific value of the blend. The higher calorific value means that the blend can release more energy per unit, enabling more effective combustion and a more significant heat release, which ultimately improves combustion efficiency.



a. For CSOME **b. For TSOME** **c. For TCOME**

Fig. 5. Variation of Net heat release rate with respect to Crank angle for conventional engine

The peak values of Net Heat Release Rate (NHRR) in a Low Heat Rejection (LHR) engine vary across all load levels compared to a conventional engine. Using biodiesels and their blends produces NHRR values closer to diesel, particularly under high load conditions. This similarity is attributed to an increased fuel injection quantity and improved combustion efficiency from the higher oxygen content in the biodiesel blends. At higher loads, the elevated in-cylinder temperature enables better combustion of biodiesel, despite its lower calorific value. With increasing load, peak NHRR values for the LHR engine reach 20.04, 15.81,and 25.29 J/°CA for CSOME, TSOME, and TCOME, respectively shown in figure 6. These findings indicate that incorporating CSOME with TSOME enhances the combustion rate and subsequently raises the heat release rate, thanks to the boost in calorific value.



a. For CSOME **b. For TSOME** **c. For TCOME**

Fig. 6. Variation of Net heat release rate with respect to Crank angle for LHR engine

In conclusion, the study highlights that the Low Heat Rejection (LHR) engine, when using biodiesel blends,achieves peak Net Heat Release Rate (NHRR) values that are competitive with conventional diesel engines,particularly under higher load conditions. This performance is largely due to the improved combustion efficiency stemming from the biodiesel's oxygen content and the enhanced in-cylinder temperature of the LHR engine. Additionally, combining CSOME with TSOME appears to further boost combustion rates and heat release, driven by the resulting increase in calorific value. These findings suggest that biodiesel blends can be effectively utilized in LHR engines to achieve improved combustion characteristics, making them apromising alternative for reducing emissions while maintaining engine performance.

4. Conclusions

This study presents an experimental investigation into the combustion characteristics of Low Heat Rejection (LHR) and conventional engines when fuelled with blends of Tobacco Seed Oil Methyl Ester (TSOME) and Cotton Seed Oil Methyl Ester (CSOME). The research focuses on evaluating critical combustion parameters, including in-cylinder pressure and Net Heat Release Rate (NHRR), under varyingengine loads.

- The Low Heat Rejection (LHR) engine fuelled with biodiesel blends shows combustion characteristics similar to conventional diesel, particularly under high load conditions.
- Peak in-cylinder pressures were consistently higher in the LHR engine due to enhanced heat retention, which improved combustion efficiency compared to the conventional engine.
- Biodiesel blends of Cottonseed Oil Methyl Ester (CSOME) and Tobacco Seed Oil Methyl Ester (TSOME) demonstrated shorter ignition delays, which contributed to quicker combustion initiationin the LHR engine.

- The addition of CSOME to TSOME raised the combustion rate and Net Heat Release Rate (NHRR) due to the blend's increased calorific value, improving overall combustion performance.
- Higher oxygen content in biodiesel blends enhanced fuel oxidation, leading to more complete combustion and aligning the peak NHRR values of biodiesel blends closely with those of diesel fuel, particularly in the LHR engine.
- The use of biodiesel blends in the LHR engine resulted in more effective fuel utilization and potentially lower emissions, offering a sustainable alternative for conventional diesel engines.

Abbreviations and Nomenclature

CSOME	**Cotton seed oil methyl ester**
TSOME	**Tobacco seed oil methyl ester**
ID	**Ignition delay**
LHR	**Low heat rejected**
TCOME	**Tobacco and Cotton seed oil methyl ester blend**

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